

Observation-based Cloud Radiative Kernels from A-Train

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Cloud Radiative Forcing (CRF) and Cloud Radiative Kernel (CRK)

$$CRF = F_{clr} - F_{all_sky} = C(F_{clr} - F_{ovc}).$$

CRF: Cloud Radiative Forcing C: Cloud fraction

F_{clr} : clear-sky TOA flux F_{ovc} : overcast-sky TOA flux

$$K \equiv \partial CRF / \partial C$$

K: Cloud Radiative Kernel to directly access the cloud radiative feedback by cloud type using the concept of radiative kernel

First proposed by Zelinka et al. (2012) to determine directly the cloud feedback by ISCCP CTP- τ cloud types

- Cloud type defined as ISCCP CTP- τ histogram
- Fu and Liou model.
- Zonal and monthly mean T and Q profiles from control runs of 6 GCM
- Assuming plane parallel single-layer overcast cloud, with synthetic cloud and surface properties.
- “Clear sky”: cloud-removed.

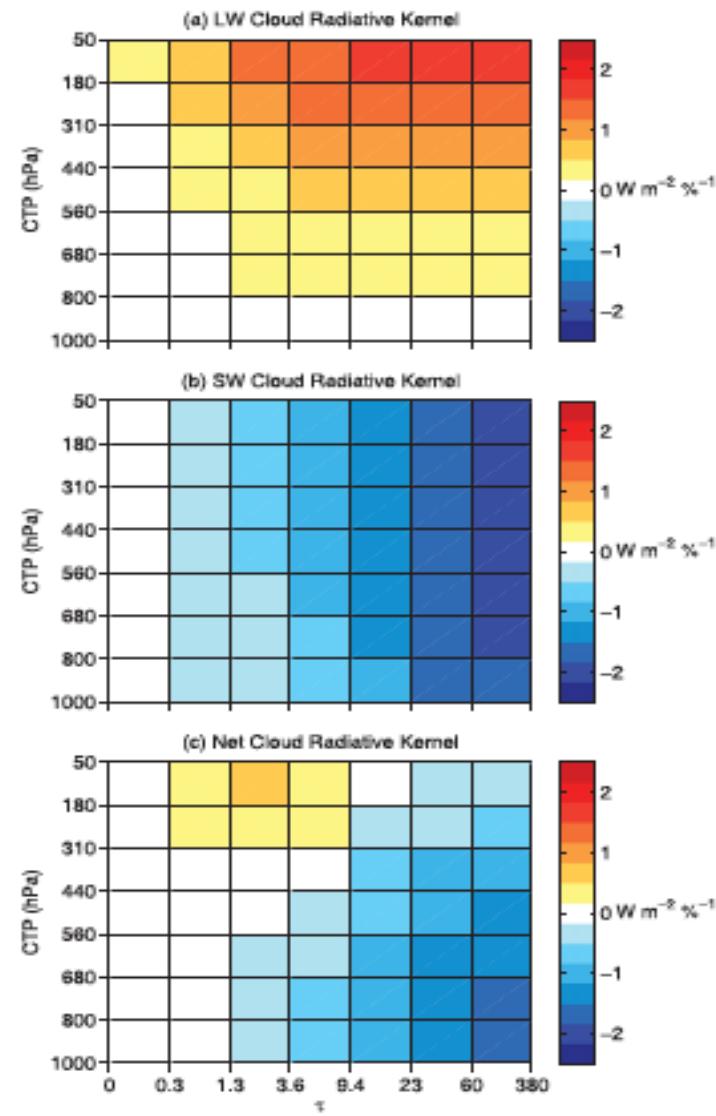
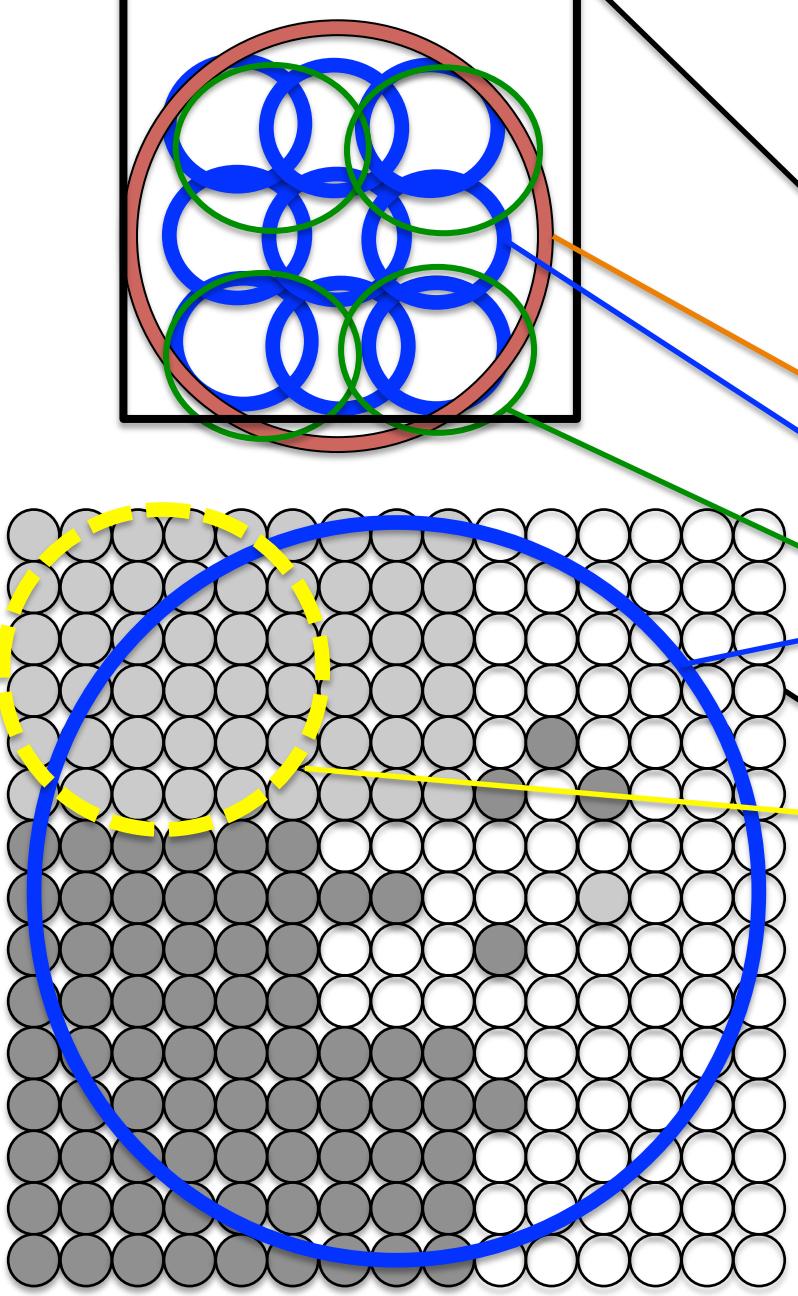


FIG. 1. Global, annual, and ensemble mean (a) LW, (b) SW, and (c) net cloud radiative kernels. In each model, the kernels have been mapped to the control climate's clear-sky surface albedo distribution before averaging in space; thus, the average kernels are weighted by the actual global distribution of clear-sky surface albedo in each model.

Pixel-scale Collocated Multi-Satellite Obs. and Reanalysis



MERRA reanalysis (1.25X1.25, 3-hrly)
MERRA reanalysis (1/2 X 2/3, hourly)

AIRS/AMSU L2 Retrieval (45 km)

AIRS cloud and radiances, SOLRs (13 km)

CERES TOA fluxes (20km) and CERES-MODIS cloud properties

MODIS cloud mask (1km)
MODIS Level 2 cloud retrieval (1 and 5km)

CloudSat

Collocated radiation, atmospheric thermodynamic, dynamics, and surface condition and their correspondent cloud condition data

From Satellite Data

Observation-based CRKs

1. Standard MODIS cloud (MAST-MODIS), CERES flux, AIRS ECF.
2. CERES flux and CERES-MODIS cloud.
3. AIRS spectral longwave CRK.

$$\Delta \text{CRF} = \text{CRF[observed.clear]} - \text{CRF[cloud.removed]}$$
$$= C(F_{\text{clr}}[\text{observed.clear}] - F_{\text{clr}}[\text{cloud.removed}]).$$

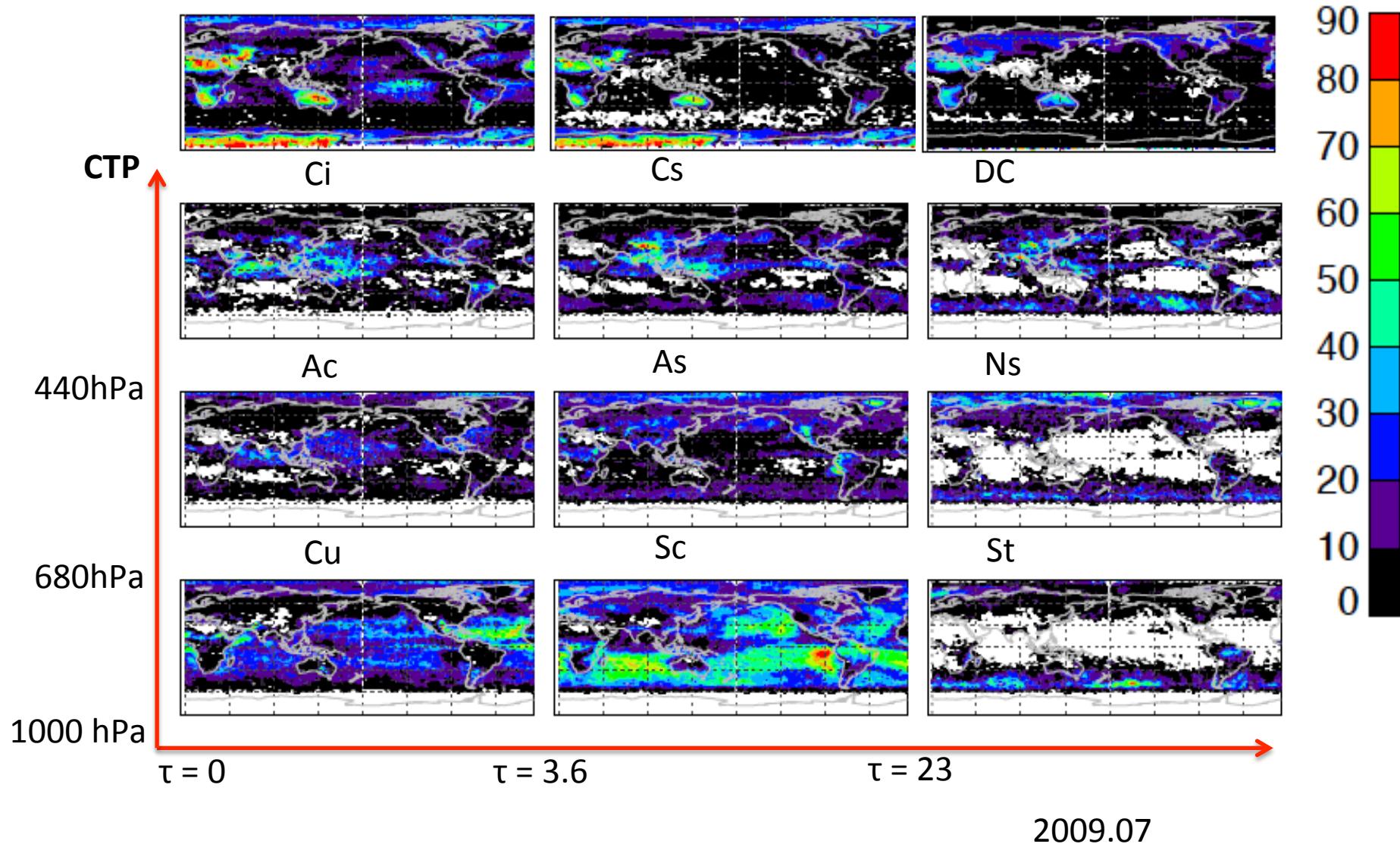
Model-based CRK with obs components:

- Using Fu and Liou.
- Cloud from MODIS and CloudSat by cloud type that is collocated with atmosphere and flux data.
- MERRA reanalysis: MERRA surface and atmosphere (MERRA F_{clr}) classified by MODIS CTP- τ cloud histogram
- Observed Clear-sky: AIRS ECF < 0.01
- Cloud-removed atmospheric column.

Quantify Uncertainties: contribution from atmosphere in CRF, different MODIS cloud retrieval algorithms, different definitions of clear sky, assumption of single layer cloud

Global Distribution of The Occurrence Frequency For Clear Sky and Different Cloud Types

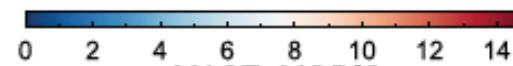
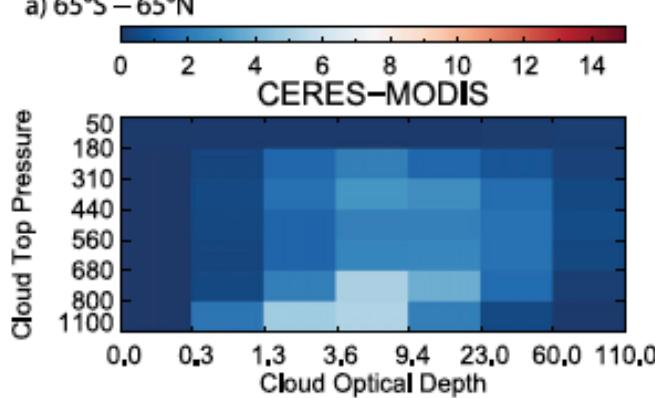
Clear1: AIRS ECF < 0.05 Clear2: AIRS ECF < 0.01 Clear3: MOD CF < 0.05



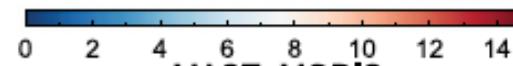
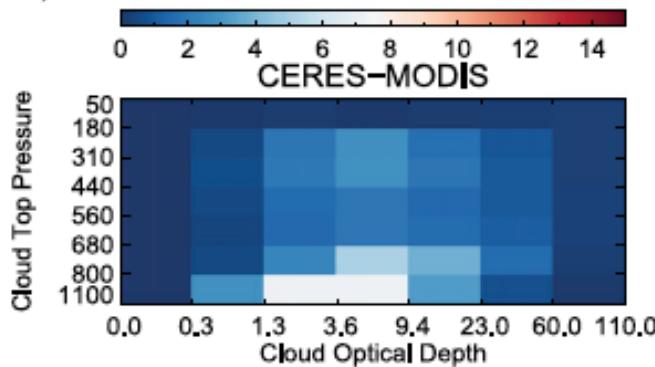
Same Instrument but Different Retrieval Algorithm

View Cloud Differently

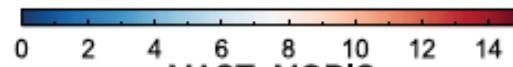
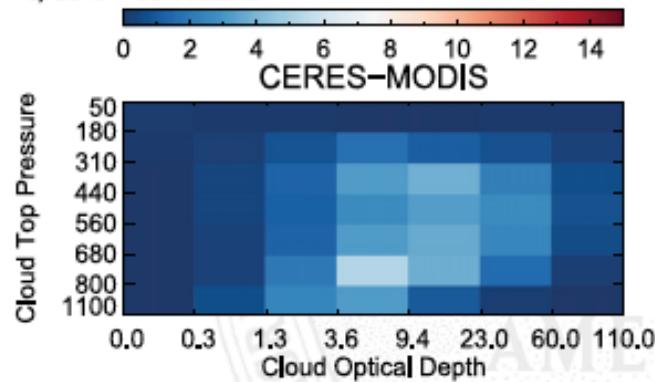
a) 65°S – 65°N



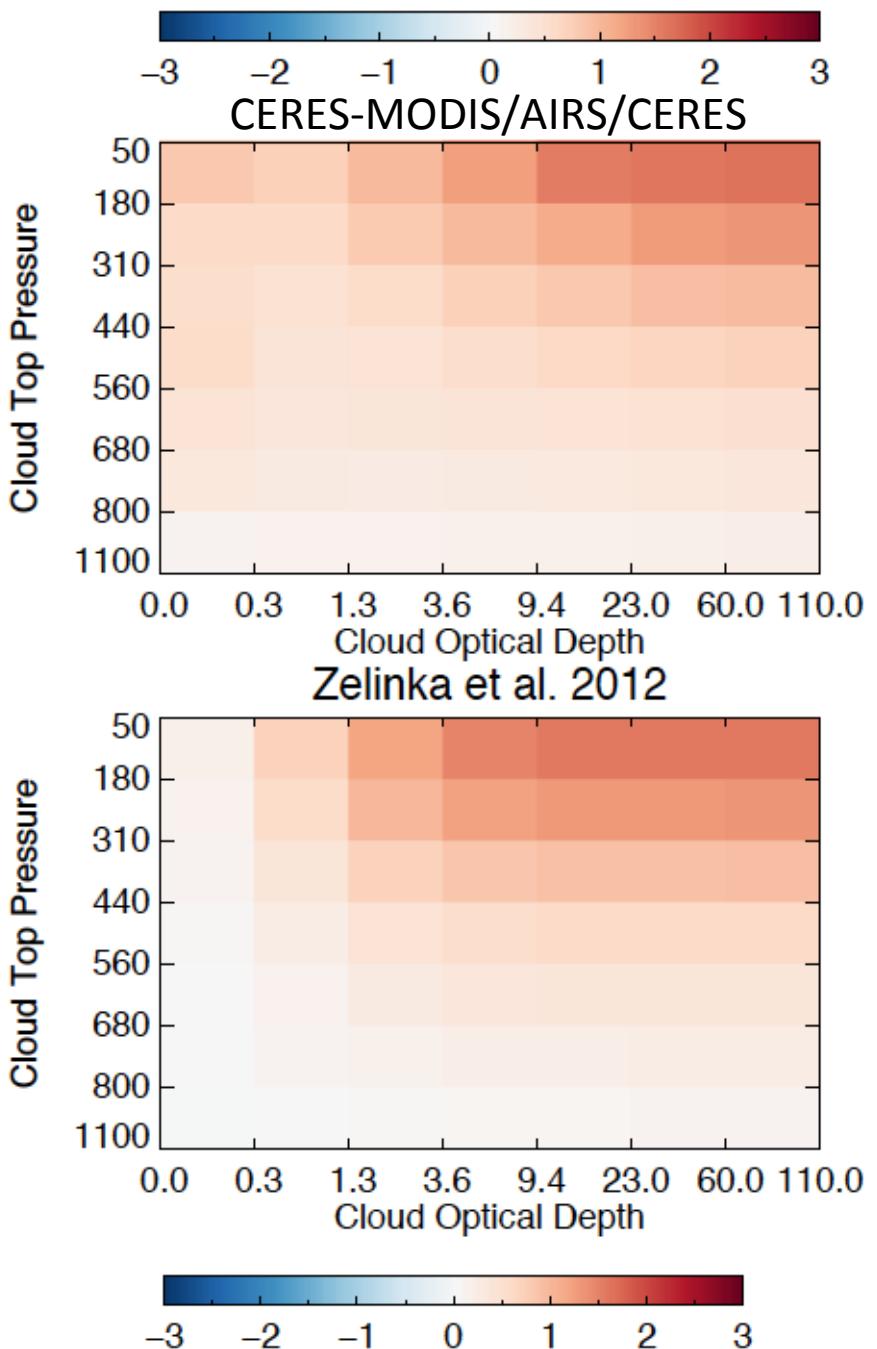
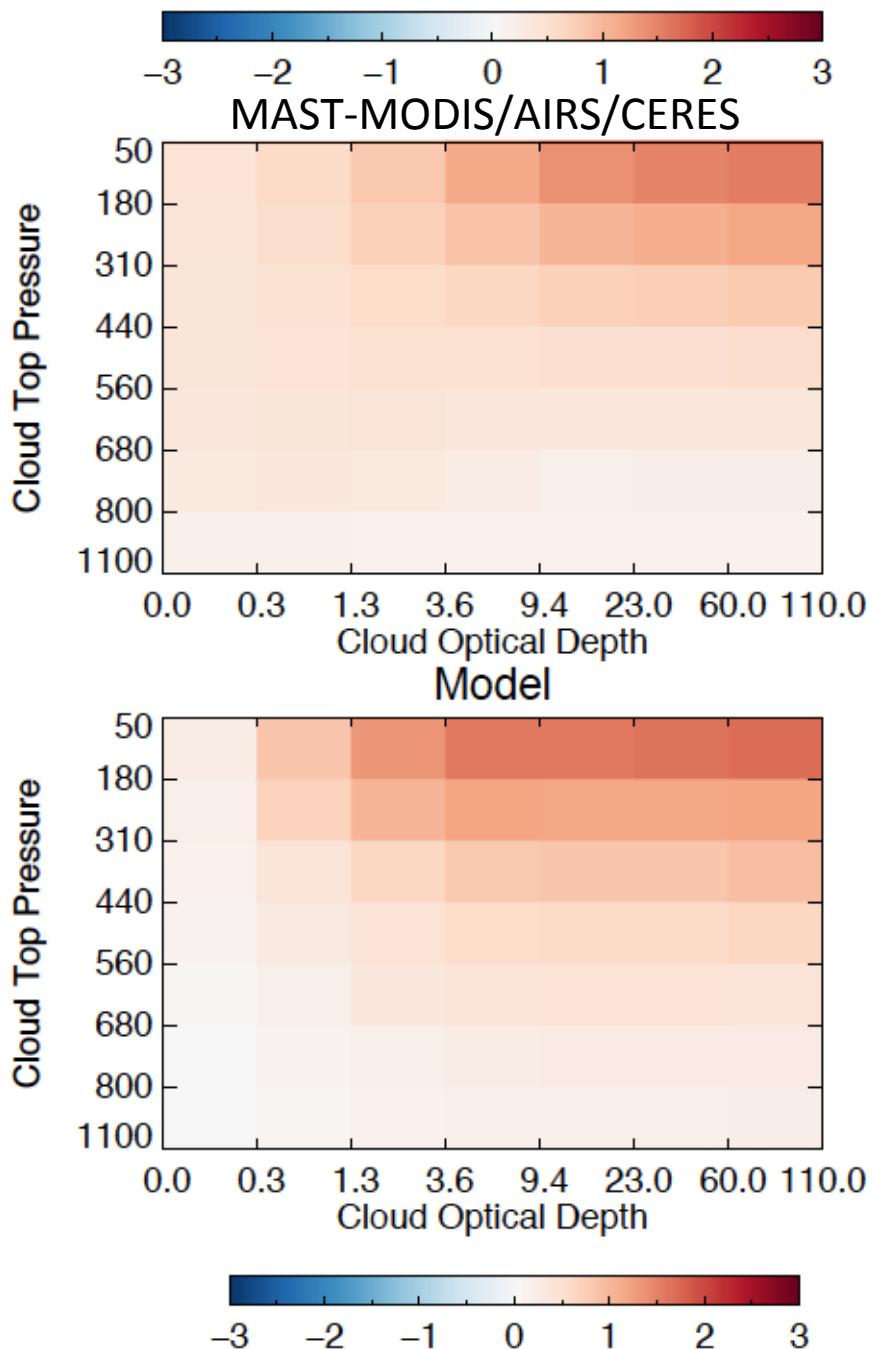
b) 65°S – 65°N Ocean



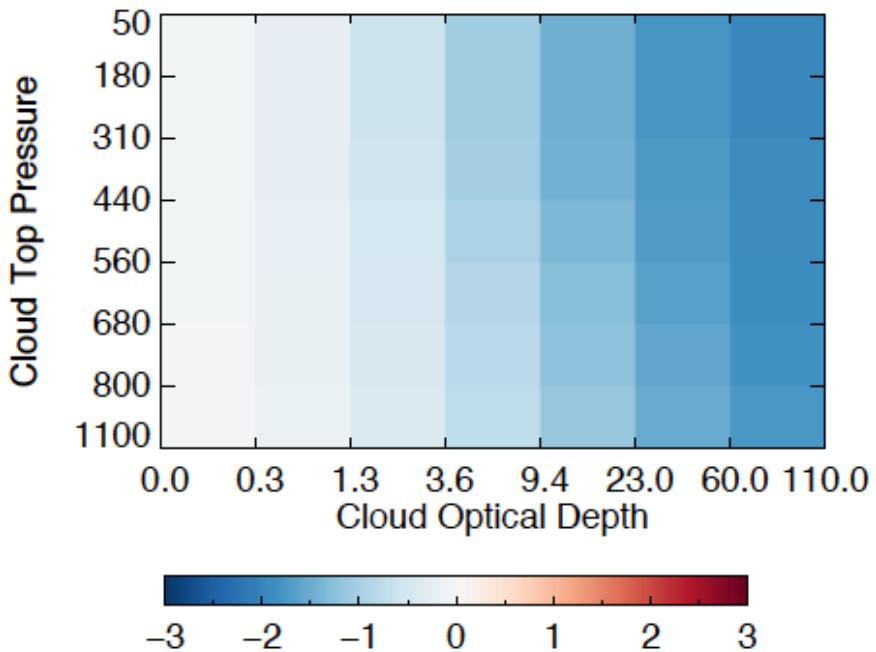
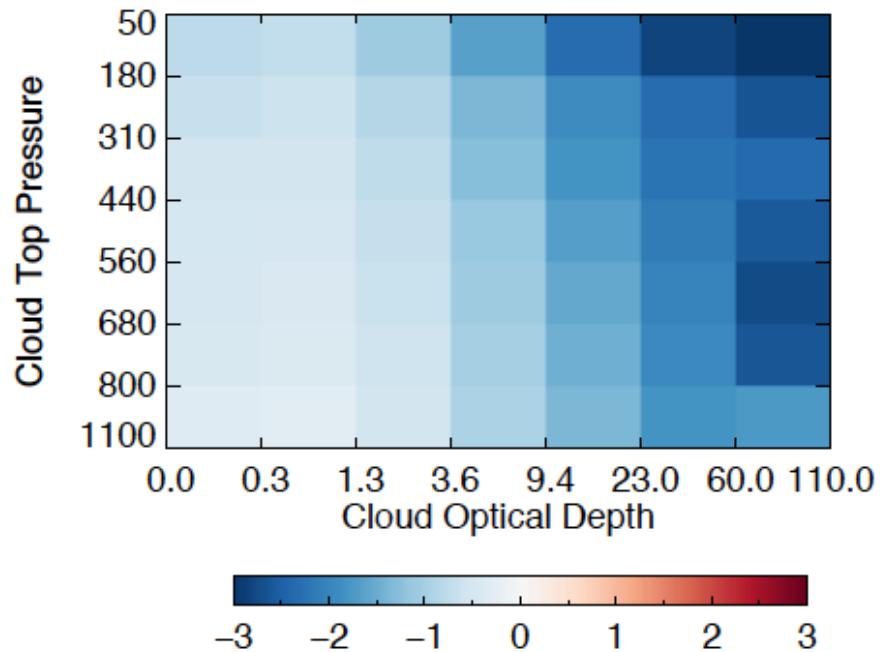
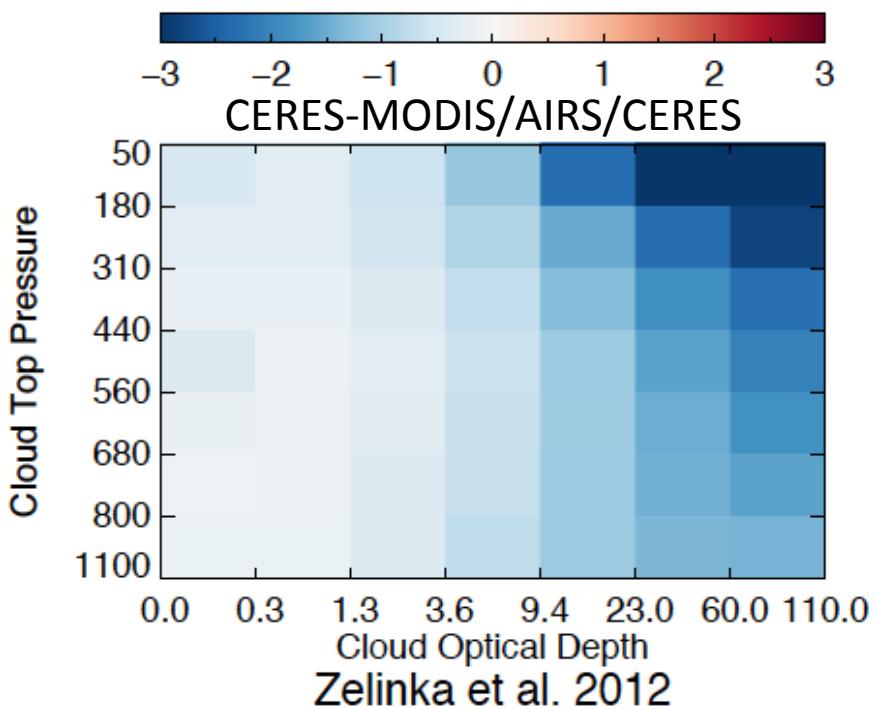
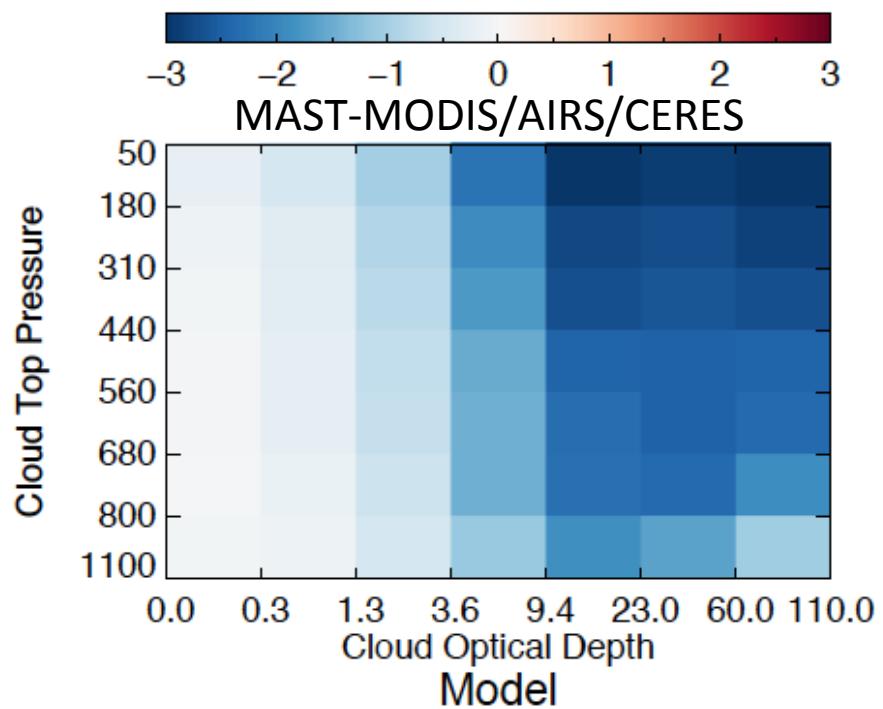
c) 65°S – 65°N Land



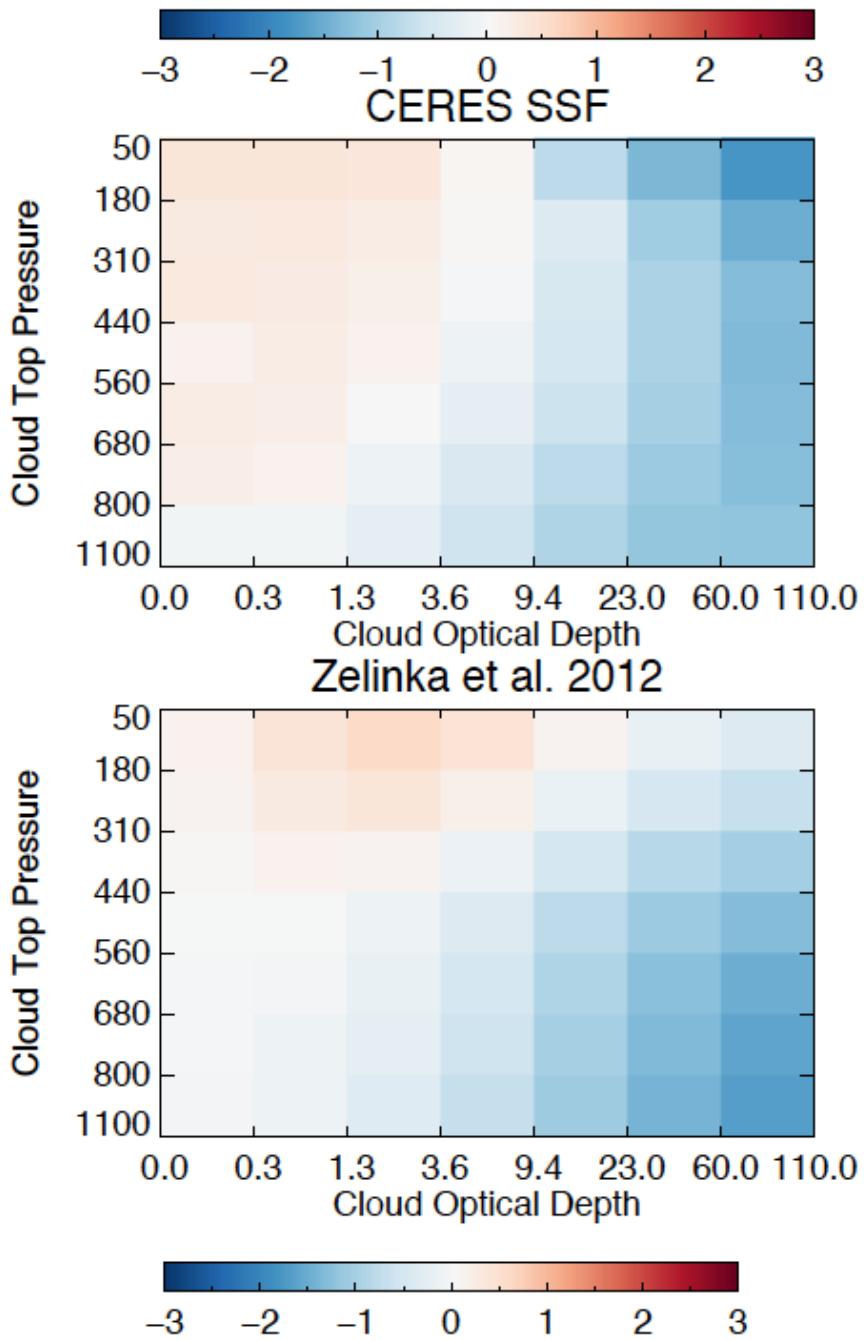
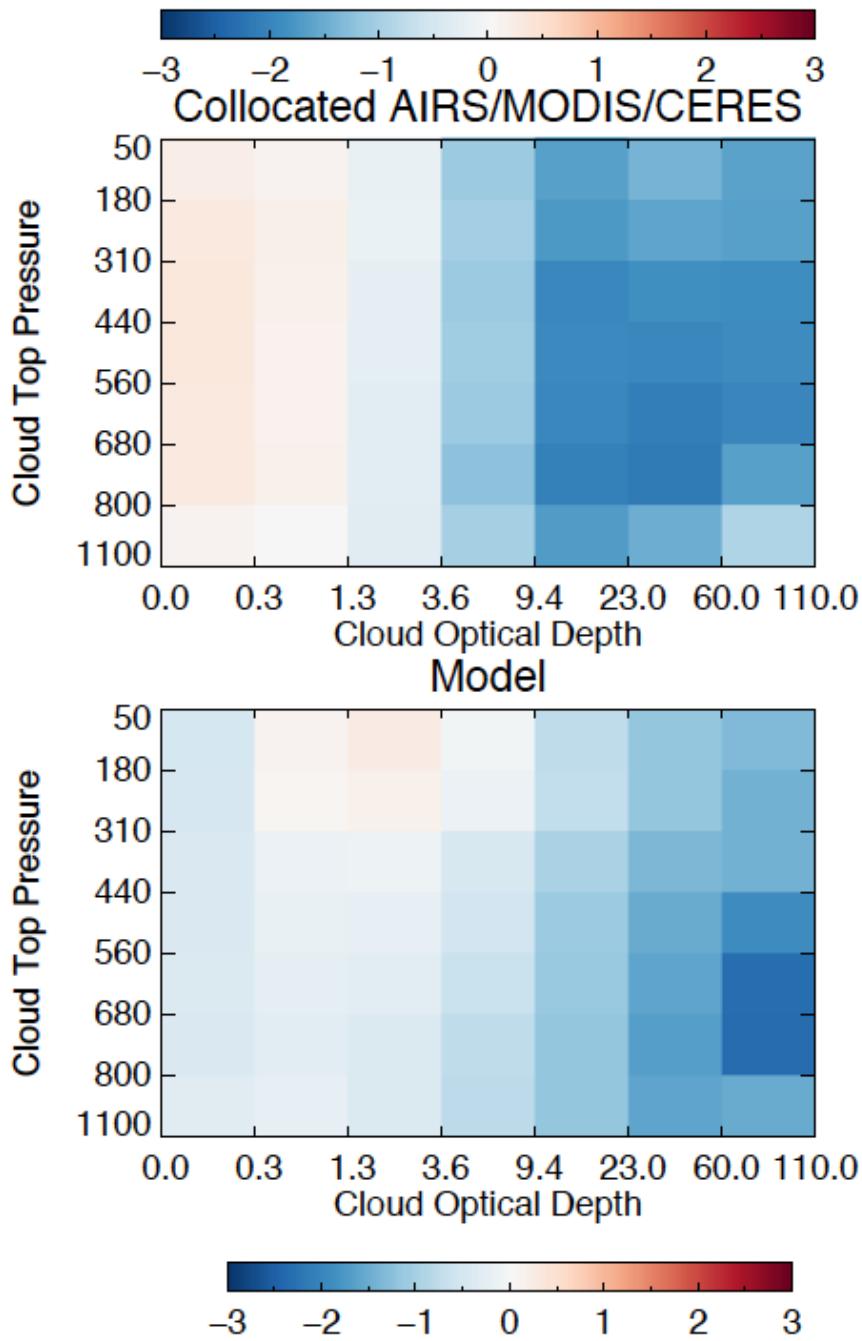
Broadband Longwave CRKs



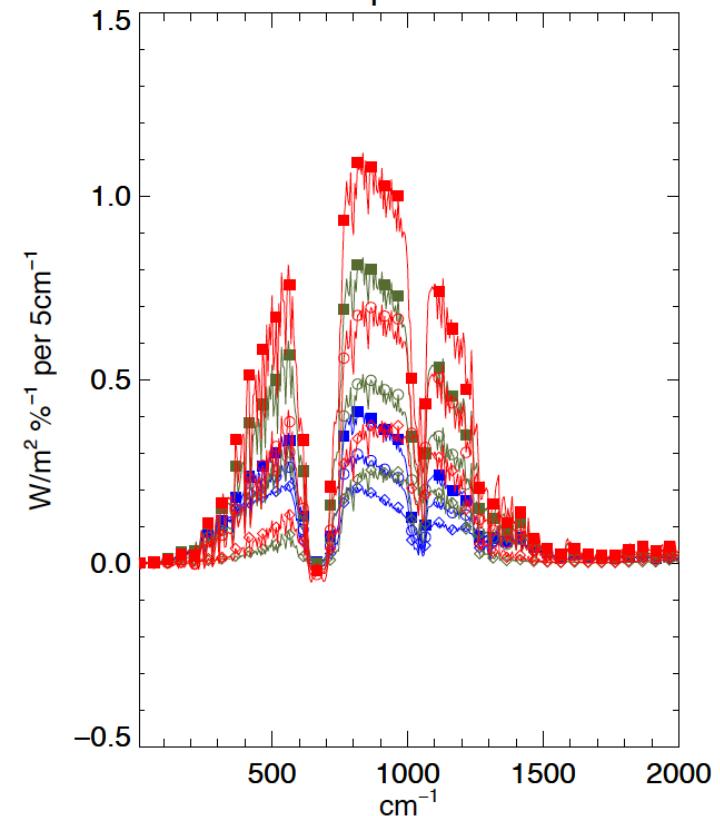
Shortwave CRKs



Net Kernel



AIRS Spectral CRK



Spectral Longwave CRKs from Reconstructed AIRS SOLR Data

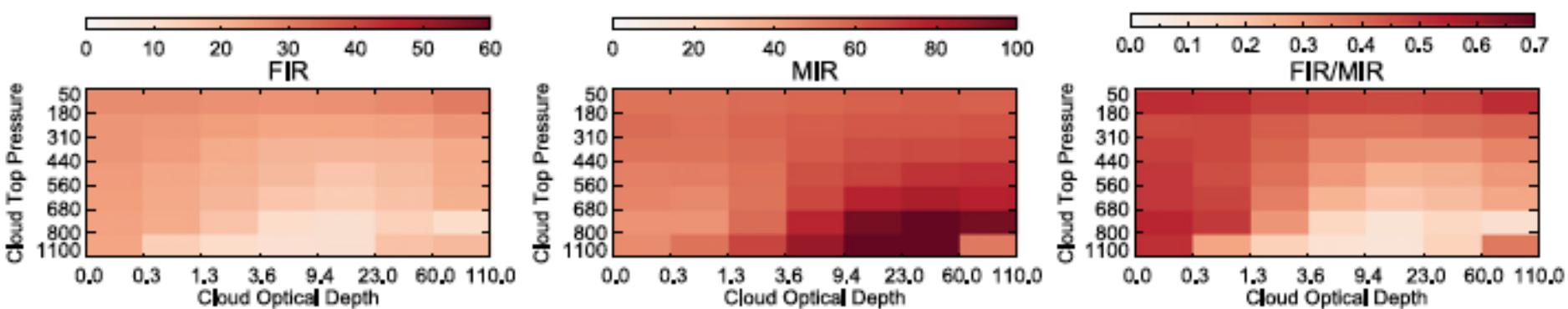
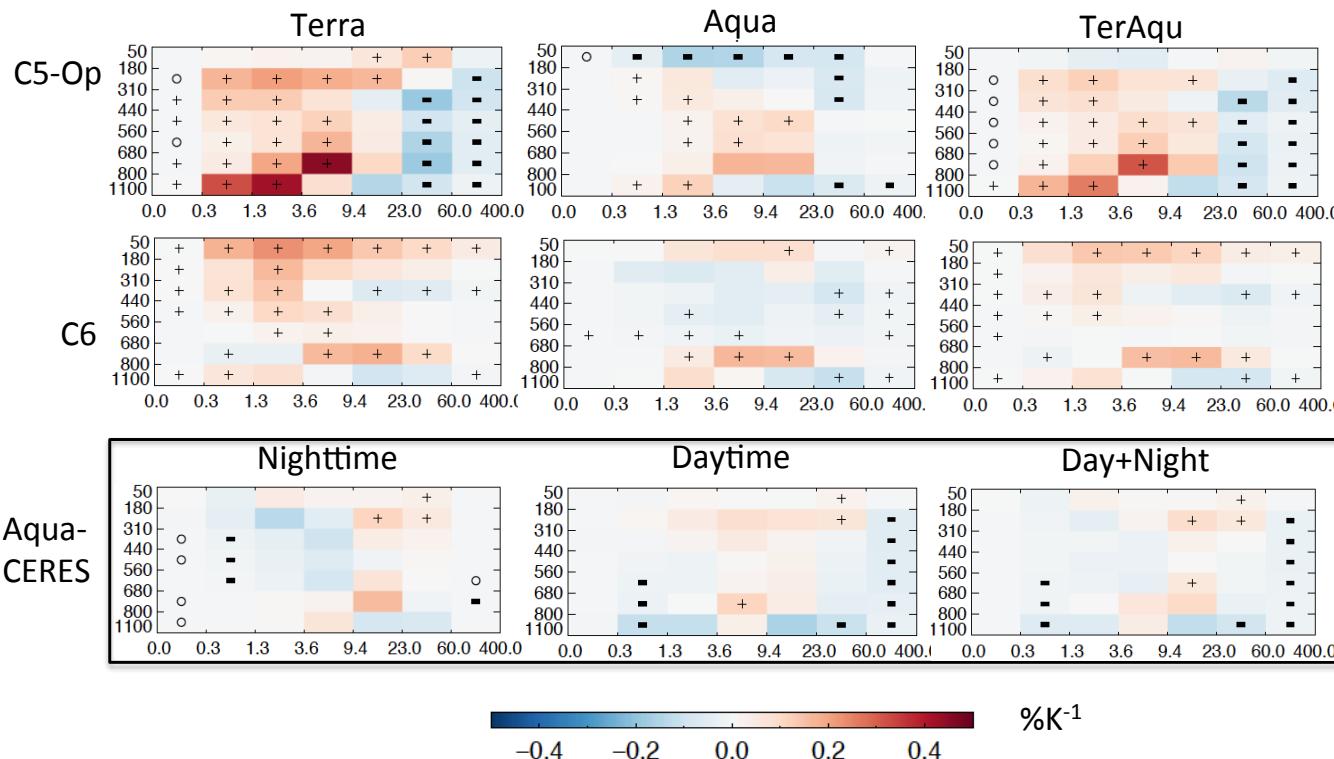


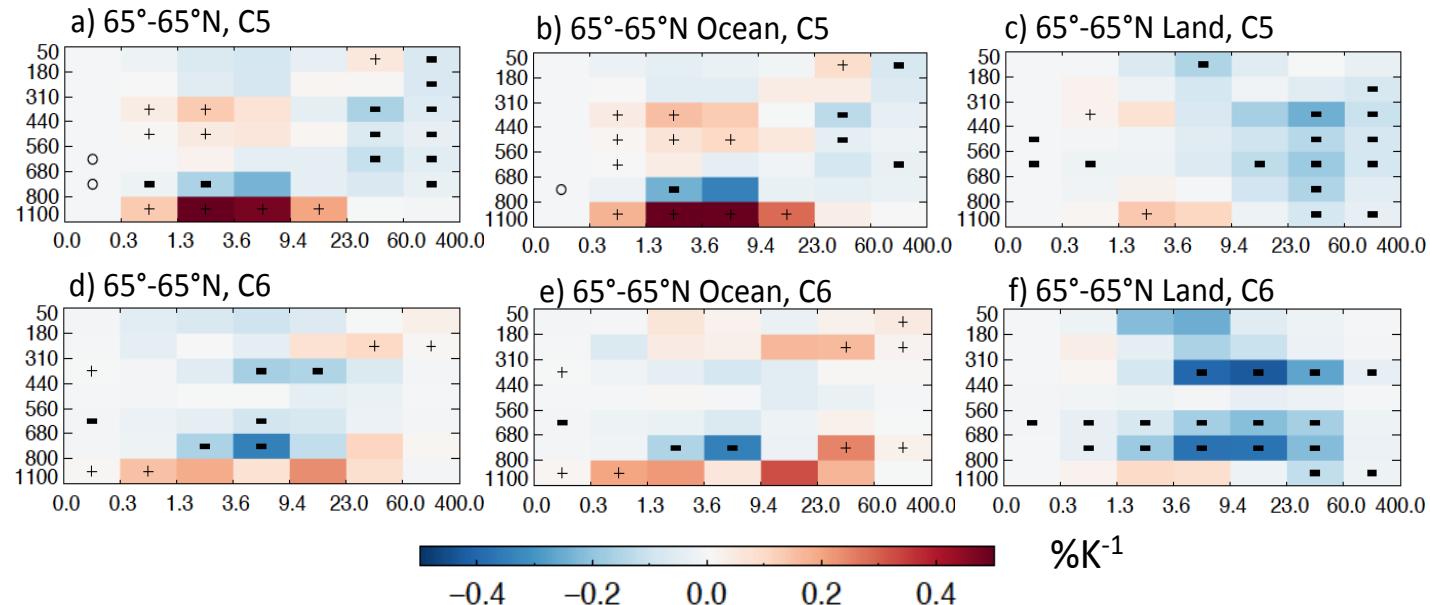
FIG. 11. Percentage of AIRS spectral CRK by cloud type contributed from two separate infrared spectral regions: (left) FIR ($>14 \mu\text{m}$) and (center) MIR (5–12 μm). (right) The ratio between the FIR and MIR.

ΔT_s -Mediated Cloud Response from Satellites



Slope of the linear regression of cloud-cover anomaly in each CTP- τ bin and global mean ΔT_s anomaly ($\% \text{K}^{-1}$). Cloud observations from -65° to 65° latitude band from **July 2002 to June 2015** are used in the analysis. Y-axis shows CTP in hPa and x-axis shows τ . Bins where the regression slope is statistically significant (>95%) are marked with symbols. "+" indicates a positive response (slope $> 1.0 \times 10^{-3}$), "-" a negative response (slope $< -1.0 \times 10^{-3}$), and "o" a neutral response ($-1.0 \times 10^{-3} < \text{slope} < 1.0 \times 10^{-3}$).

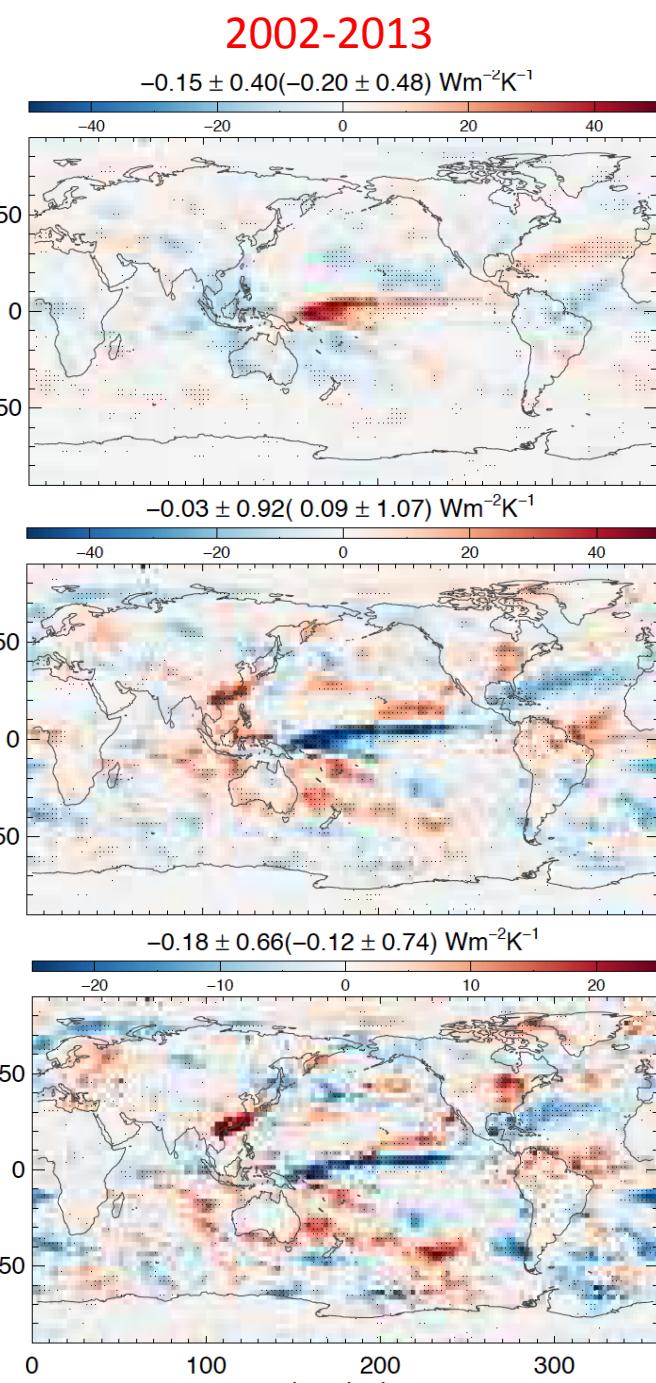
A-Train Era Before 2011 Cloud Response from Satellites



A-Train Short-term Cloud Feedback

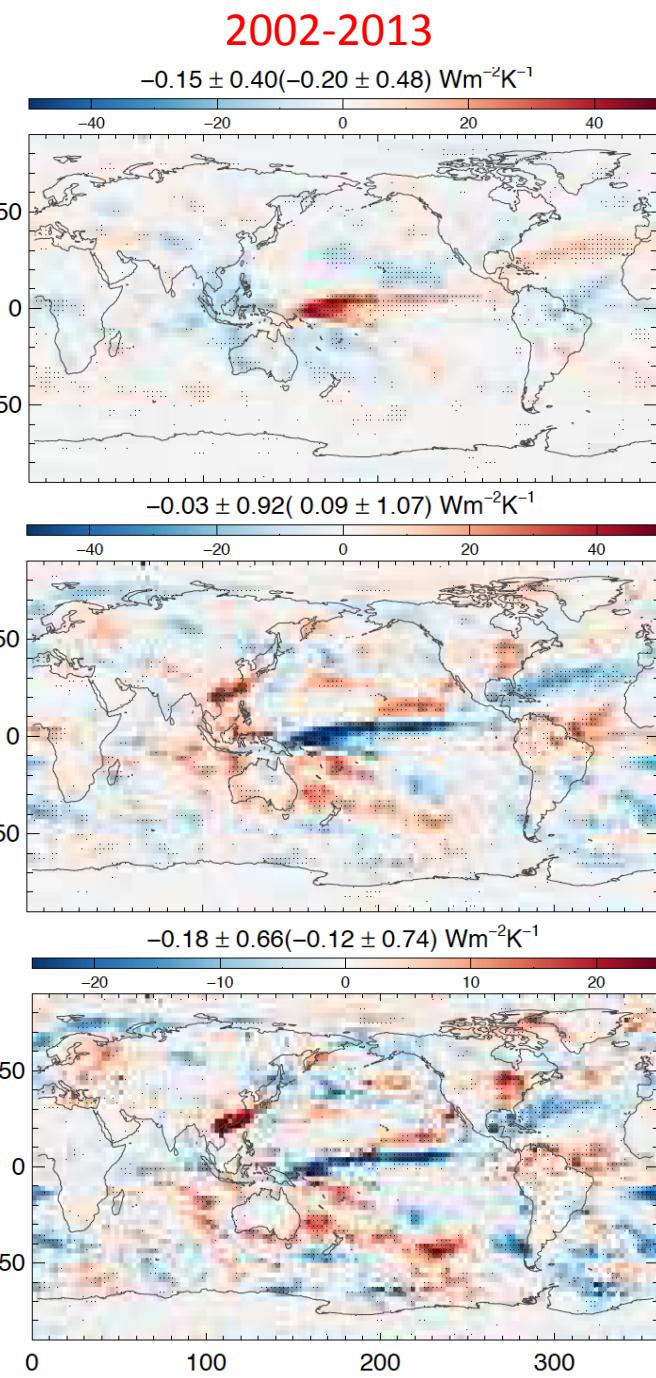
LW

Latitude



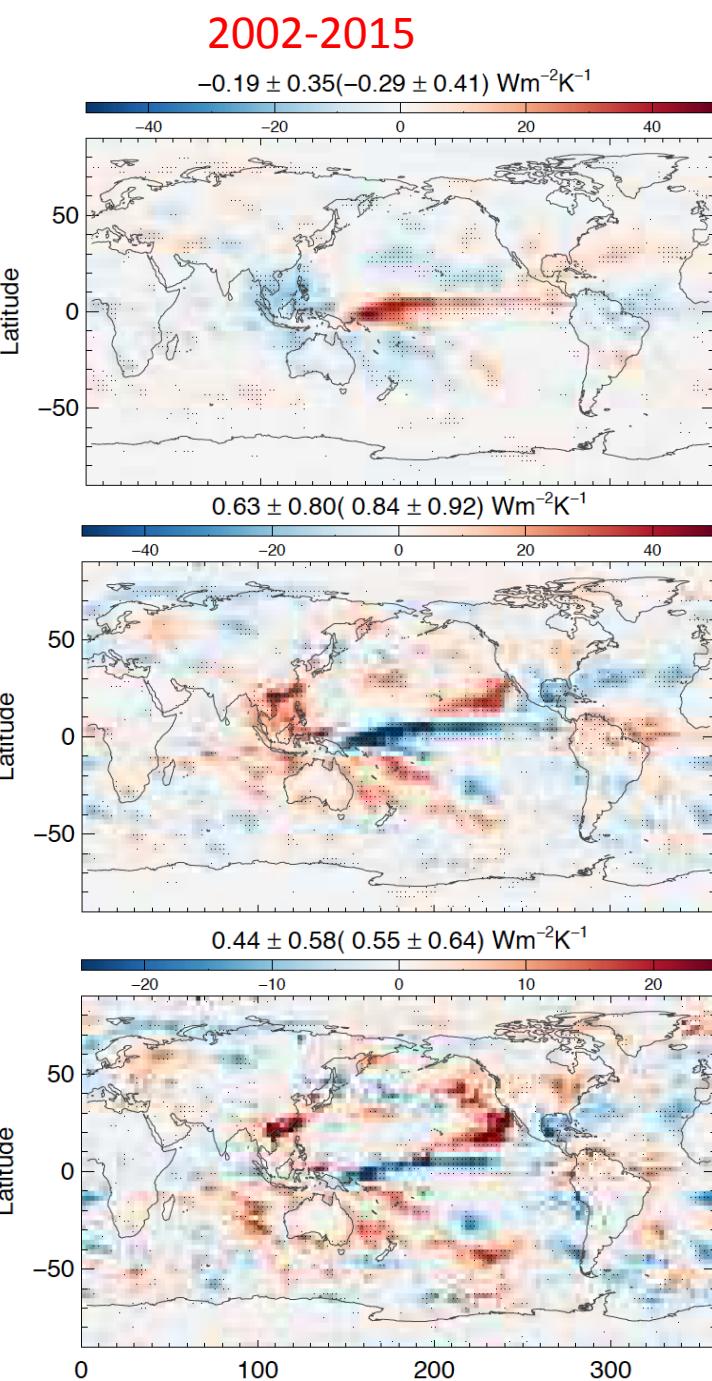
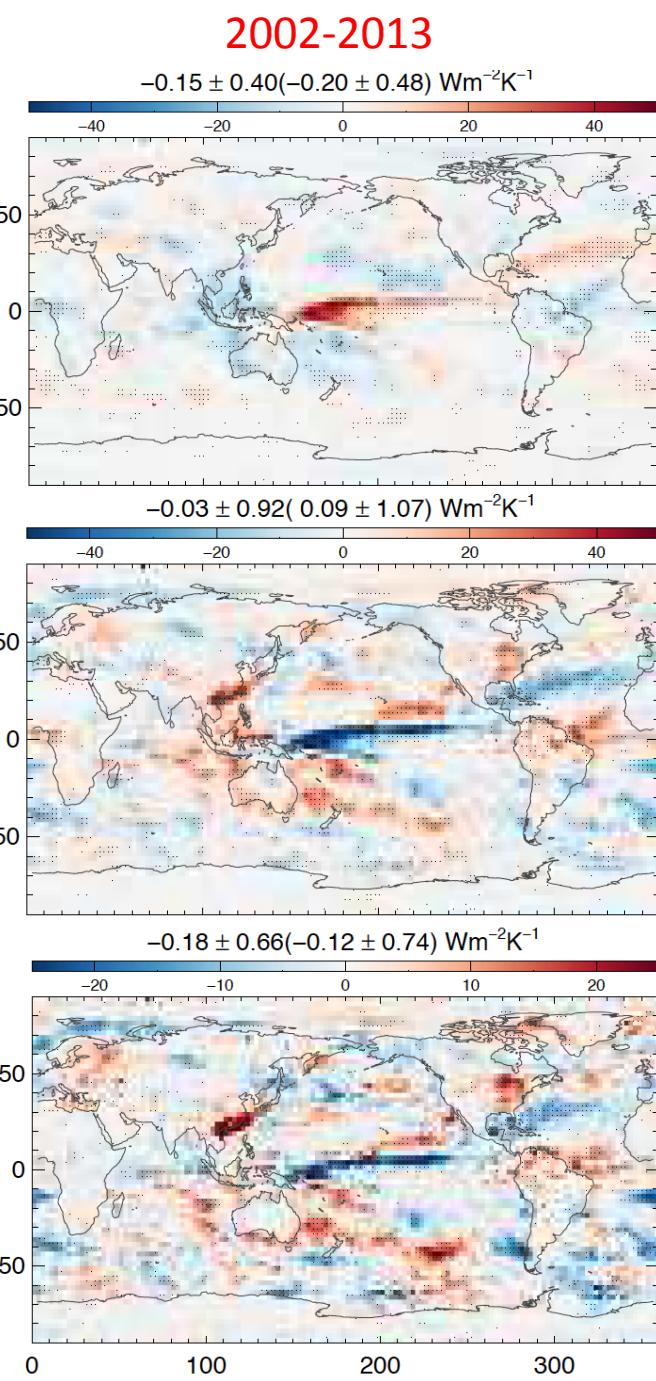
SW

Latitude



Net

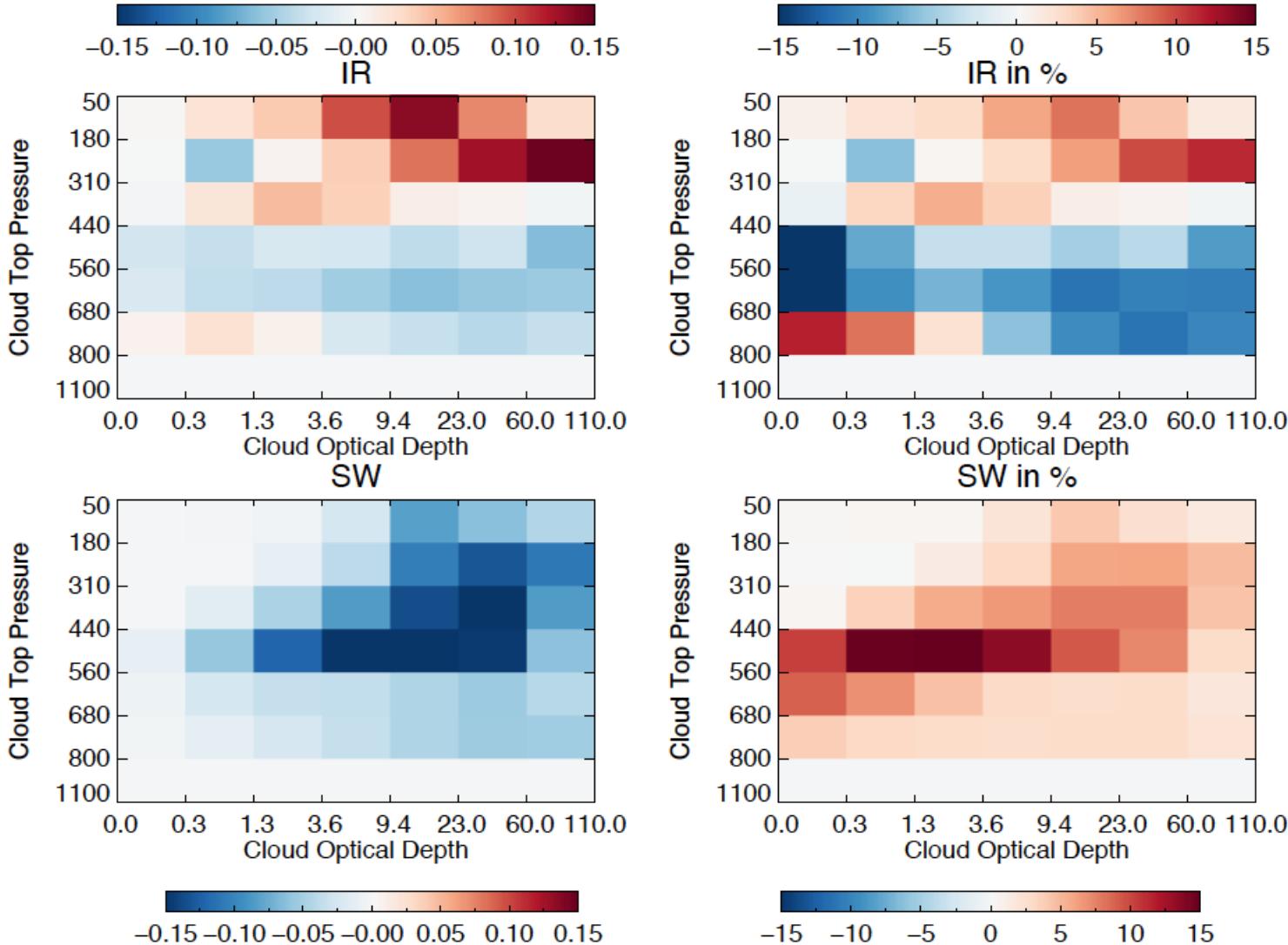
Latitude



Summary

- We develop a method to empirically derive broadband and spectral cloud radiative kernels by cloud type from pixel-scale collocated A-Train observations and reanalysis, which does not require additional cloudy radiative transfer calculations nor cloud properties.
- This method is able to estimate the cloud feedback by maintaining the consistency between CRKs and cloud responses.
- ΔT_s -Mediated Cloud Response from Satellites shows sensitivity to satellite orbit and analyzed data period.

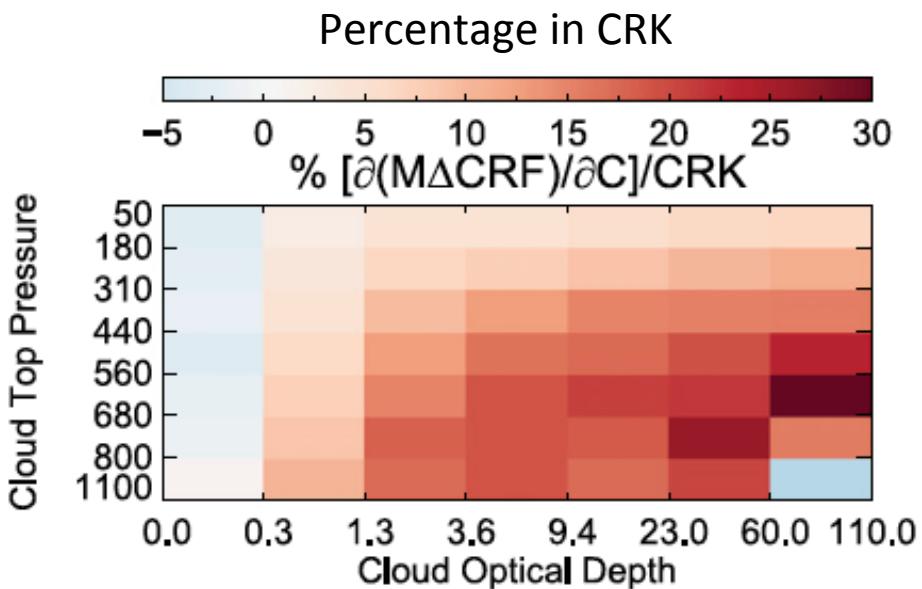
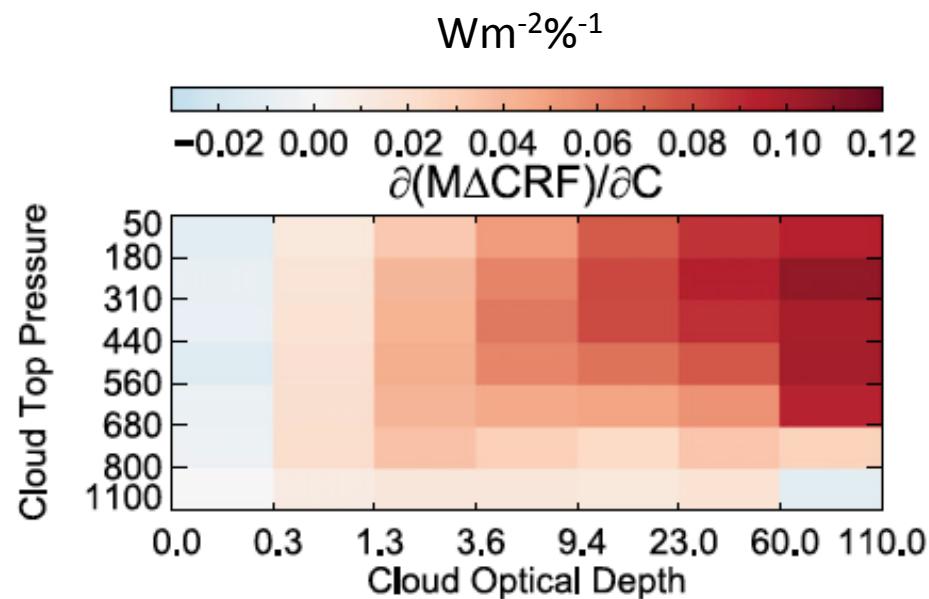
Uncertainties Due to Cloud Vertical Structure



Single-layer minus cloud profile: monthly mean cloud-type-dependent cloud optical depth vertical profiles are used in the radiative transfer calculation.

The Atmospheric Component in the Cloud Radiative Forcing Estimated From Observations

$$\begin{aligned} M\Delta CRF &= CRF[\text{observed.clear}] - CRF[\text{cloud.removed}] \\ &= C(F_{clr}[\text{observed.clear}] - F_{clr}[\text{cloud.removed}]). \end{aligned}$$



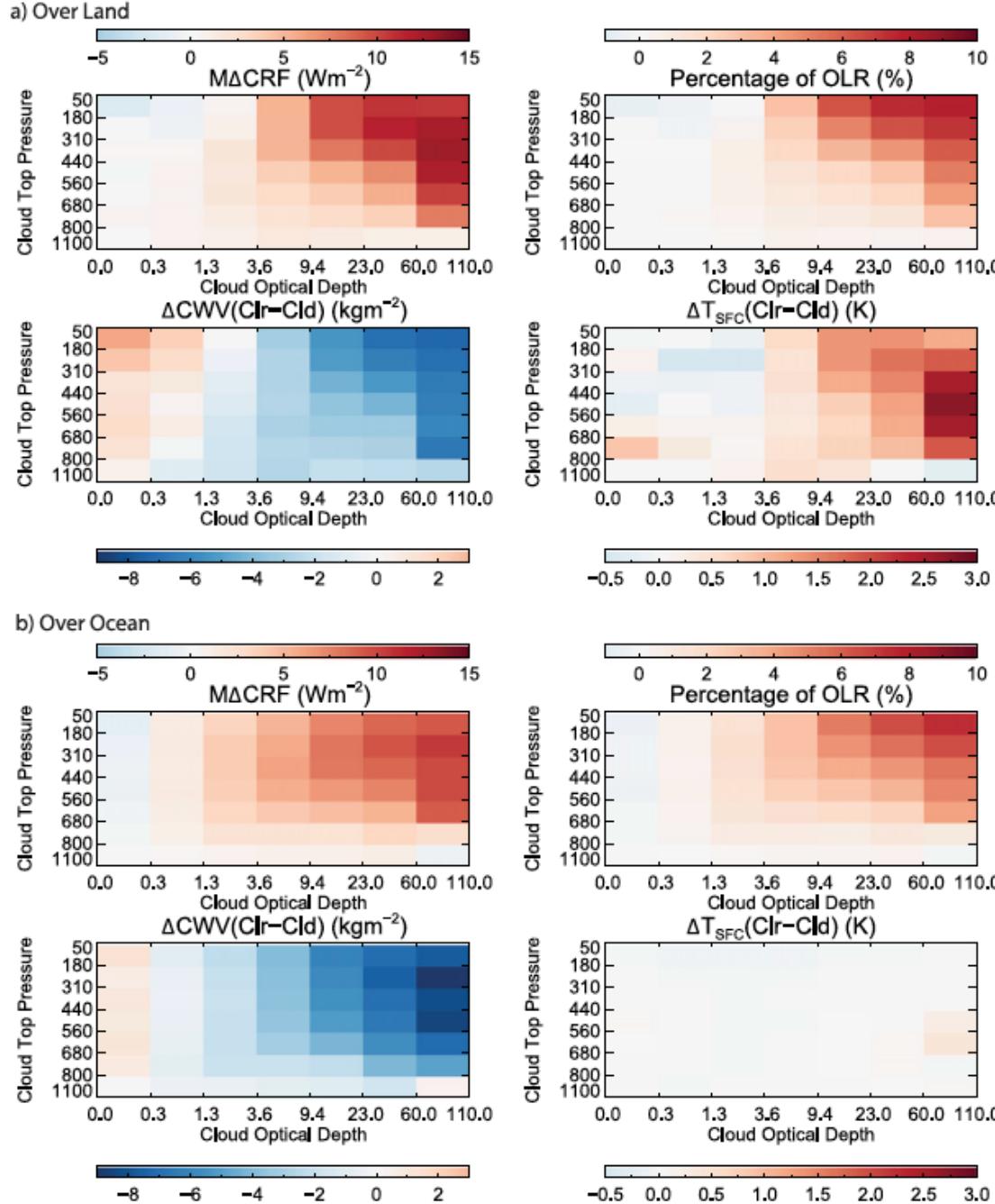


FIG. 4. MΔCRF by cloud type that is caused by the difference in clear and cloudy atmosphere states for 65°N–65°S over (a) land and (b) ocean. Also shown are the percentages of the MΔCRF in OLR and the ΔT_{SFC} and ΔCWV by cloud type between clear and cloudy atmospheric columns.

Radiative Kernel

$$\lambda_X = - \frac{\delta_X \bar{R}}{\delta X} \frac{\delta X}{\delta T_s}$$

Climate feedback parameter for variable X

Radiative kernel of X: Base climate state and radiative transfer

Climate response term: change of X between two climate states directly related to a specific feedback

X: water vapor, temperature, surface albedo.

If X=Cloud, nonlinearities in the radiative transfer of cloud due to the cloud vertical distributions, prohibiting the use of perturbation method.

Since A-Train observes everything, can we derive kernels independent of model simulations and radiative transfer models?

